AFRL-HE-WP-TP-2005-0017

# AIR FORCE RESEARCH LABORATORY

## Wireless Communication Technology As Applied to Head Mounted Display For a Tactical Fighter Pilot

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**November 2005**

20060403512



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# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



**1. REPORT DATE** *(DD-MM-YYYY)*
November 2005

**2. REPORT TYPE**
Technical Paper

**3. DATES COVERED** *(From - To)*

**4. TITLE AND SUBTITLE**
Wireless Communication Technology as Applied to Head Mounted Display for a Tactical Fighter Pilot

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**
65502F

**6. AUTHOR(S)**
Gurdial Saini

**5d. PROJECT NUMBER**
3005

**5e. TASK NUMBER**
HC

**5f. WORK UNIT NUMBER**
45

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)**

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Air Force Materiel Command
Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
Wright-Patterson AFB OH 45433-7022

**10. SPONSOR/MONITOR'S ACRONYM(S)**
AFRL/HECV

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**
AFRL-HE-WP-TP-2005-0017

**12. DISTRIBUTION / AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

**13. SUPPLEMENTARY NOTES**
This will be published in the Proceedings of the SPIE Defense & Security Symposium Conference. The clearance number is AFRL/WS-05-2635, cleared 15 November 2005.

**14. ABSTRACT**
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**15. SUBJECT TERMS**
Head Mounted Display, Wireless Communication

| 16. SECURITY CLASSIFICATION OF: a. REPORT | b. ABSTRACT | c. THIS PAGE | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| UNC | UNC | UNC | SAR | 19 | Gurdial Saini |
| | | | | | **19b. TELEPHONE NUMBER** *(include area code)* (937) 255-8868 |

**Standard Form 298 (Rev. 8-98)**
**Prescribed by ANSI Std. 239.18**

# Wireless Communication Technology as applied to Head Mounted Display for a Tactical Fighter Pilot

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ABSTRACT: The use of Helmet-Mounted Display/Tracker (HMD/Ts) is becoming widespread for air-to-air, within visual range target acquisition for a tactical fighter pilot. HMD/Ts provide the aircrew with a significant amount of information on the helmet, which reduces the burden of the aircrew from having to continually look down in the cockpit to receive information. HMD/Ts allow the aircrew to receive flight and targeting information regardless of line-of-sight, which should increase the aircrew's situation awareness and mission effectiveness. Current technology requires that a pilot wearing a Helmet Mounted Display/Tracker be connected to the aircraft with a cable. The design of this cable is complex, costly, and its use can decrease system reliability. Most of the problems associated with the use of cable can be alleviated by using wireless transmission for all signals. This will significantly reduce or eliminate the requirements of the interconnect cable/connector reducing system complexity, and cost, and enhancing system safety. A number of wireless communication technologies have been discussed in this paper and the rationale for selecting one particular technology for this application has been shown. The problems with this implementation and the direction of the future effort are outlined.

## 1. INTRODUCTION

Wireless networks are multi-user systems in which information is generally conveyed by radio waves. Modern wireless networks have evolved through different generations:

1G Systems. Based on analog technology, aimed at providing voice telephony services

2G Systems. Based on digital technology, aimed at providing better spectral efficiency, a more robust communication, voice privacy, and authentication capabilities

2.5G Systems. Based on 2G systems, aimed at providing the 2G systems with a better data rate capability

3G Systems. Aim at providing for multimedia services in their entirety. [1:19]

Wireless systems can be classified according to whether they have a narrowband or wideband architecture. Narrowband systems support low-bit-rate transmission, whereas wideband systems support high-bit-rate transmission. A system is defined as narrowband or wideband depending on the bandwidth of its transmission physical channels. The system bandwidth is assessed with respect to the coherence bandwidth. The coherence bandwidth is defined as the frequency band within which all frequency components are equally affected by fading due to multipath propagation phenomena. Systems operating with channels substantially narrower than the coherence bandwidth are known as narrowband systems whereas systems operating with channels substantially wider than the coherence bandwidth are known as wideband systems. [1:15]

## 2. WIRELESS LANS

Table 1 shows IEEE wireless standards. [2:54]

| | |
|---|---|
| IEEE802.11a | A physical layer standard that provides data rates of 6--54 Mbit/s over the 5 GHz frequency band. Orthogonal frequency division multiplexing (OFDM) is used to provide these high data rates and the 5 GHz band offers less RF interference compared to the 2.4 GHz band. |
| IEEE802.11b | A physical layer standard that enhances the original IEEE802.11 direct sequence spread spectrum (DSSS) to provide 11 Mbit/s data rates on top of the original 1 and 2 Mbit/s. IEEE802.11b uses the complementary code keying (CCK) modulation system to make more efficient use of the radio spectrum. |
| IEEE802.11c | Bridge operation procedures --- provides the required information to ensure proper bridging operations. Manufacturers use this standard when implementing wireless access points to ensure interoperability. |
| IEEE802.11d | Allow terminals to listen to AP transmissions and automatically set their physical layer attributes (power level, frequency, etc.) to satisfy the local regulatory domains. The work of this group is especially important for the 5 GHz spectrum as the permitted use of this band varies considerably from one country to another around the globe. |
| IEEE802.11e | This standard addresses required modifications to the medium access control (MAC) layer to provide a prioritization-based quality of service. |
| IEEE802.11f | Inter-access point protocol (IAPP) -- the communications based between access points in order to support users roaming from one AP to another. |
| IEEE802.11g | Physical layer enhancements to the 2.4 GHz band to enable high-speed (upto 54 Mbit/s) data throughput. The important proviso is that the IEEE802.11g equipment can incorporate with standard IEEE802.11b equipment on the same network. IEEE802.11g will use OFDM rather than DSSS to provide the higher data rates. |

| | |
|---|---|
| IEEE802.11h | The issues of using 5 GHz band within the European regulations. This entails providing dynamic channel selection (DCS) and transmits power control (TPC) to avoid interference with satellite communications. |
| IEEE802.11i | MAC enhancements for enhanced security -- encryption techniques such as advanced encryption standard (AES). |
| IEEE802.11j | Enhancement of IEEE802.11 standard to add channel selection of 4.9 GHz and 5 GHz in Japan in order to conform to Japanese rules of radio operation. |
| IEEE802.11k | Enable functionality for higher layers in the stack to get access to radio resource management (RRM) data captured by the PHY layer. Easier access to these measurements will enable simpler management of services (e.g., roaming, coexistence) from external systems. |
| IEEE802.11m | Maintenance of IEEE802.11 MAC/PHY specification. Update the standard documentation with technology and editorial corrections. |

Table 1. IEEE802.11 Standards

## 2.1. Ultra-Wide Band

Ultra-wideband is a relatively new technology. The term UWB was initially introduced by the US Defense Advanced Research Project Agency (DARPA). It can now be used for non-military applications. Unlike traditional narrowband systems, UWB generates short pulses and uses these pulses for data modulation. Sometimes UWB is referred to as impulse, carrierless or baseband transmission. UWB systems can transmit large amount of data at high speed over a very wide frequency spectrum with little risk of being intercepted or jammed. This makes it extremely valuable for defense applications. [2:81]

# 3. COMMUNICATION TECHNIQUES

Some of the important communication techniques are described here.

## 3.1. Multiple Access

There are three widely used techniques under multiple access. [3:395]

3.1.1. Frequency Division Multiple Access (FDMA): The available bandwidth is divided into a number of bands and individual bands assigned to individual users with a unique band or channel allocated to each user.

3.1.2. Time Division Multiple Access (TDMA): The radio spectrum is divided into time slots, and only one user is allowed to either transmit or receive in each slot.

3.1.3. Code Division Multiple Access (CDMA): The narrowband message signal is multiplied by a large bandwidth signal that has chip rate which is orders of magnitude greater than the data rate of the message. To accomplish this, *spread spectrum* is used.

3.1.3.1. Spread Spectrum Multiple Access (SSMA): In spread spectrum the intended signal is spread over a bandwidth in excess of the minimum bandwidth required to transmit the signal. The signal is encoded at the transmitter and decoded at the receiver according to a unique known scheme. A two-level modulation scheme is used. First the carrier is modulated by the baseband digital information and then the modulated signal is used to modulate the wideband function. [1:523]

3.1.3.2. Direct Sequence: In direct sequence spread spectrum, the stream of information is divided into small pieces, each of which is allocated a frequency channel across the spectrum.

3.1.3.3. Frequency Hopping: In frequency hopping, the signal in a given time slot moves from one frequency to another according to a pre-established hopping pattern. By doing so, the transmission becomes less vulnerable to fading. [1:159]

3.2. Orthogonal Frequency Division Multiplexing (OFDM)

It is a method of digital modulation in which a signal is split into several narrowband channels at different frequencies.

## 4. INTERFERENCE AND ERROR CORRECTION

4.1. Interference

Substantial radio frequency (RF) interference is inherent in all wireless systems. Interference can also be caused by equipment malfunction or as a result of enemy action using RF jammers. As a minimum, interference can introduce errors in data transmission. [4:285]

4.2. Error Correction

To make a correction to the transmitted data, the error must first be detected.

4.2.1. Error Detection

Before the data is transmitted, each packet of data is padded with additional bits known as *checksum*. The *checksum* is computed by the number of '1's and '0's in the packet to be transmitted. The *checksum* is again computed when the packet is received. If the two *checksums* match, the receiver sends back an *ACK* (*acknowledgement*) and the packet is considered to be error-free. There is no guarantee that it is error-free because the number of '1's and '0's may be same but could be disposed. On the other hand, if the two checksums do not match, the receiver sends back a *NAK* (*no acknowledgement*) and the packet in question is re-transmitted.

The *checksum* can only detect the error but cannot correct it.

4.2.2. Forward Error Correction (FEC)

When FEC is enabled, the transmitting radio adds extra bits to the data going out that allow the receiver to not only detect but also *correct* bit errors. Different levels of FEC can be enabled depending on the amount of noise in the channel and the extent of error rate that is tolerated.

## 5. COMPARATIVE ANALYSIS OF VARIOUS WIRELESS COMMUNICATION TECHNOLOGIES

The following description explains some of the technical differences between the various communication systems and shows the range of design constraints that need to be addressed. Figures 1, 2, 3, and 4 show data rate, range, power dissipation, and projected cost for various technologies. The data is taken from lecture series at University of California , Berkley. [5]

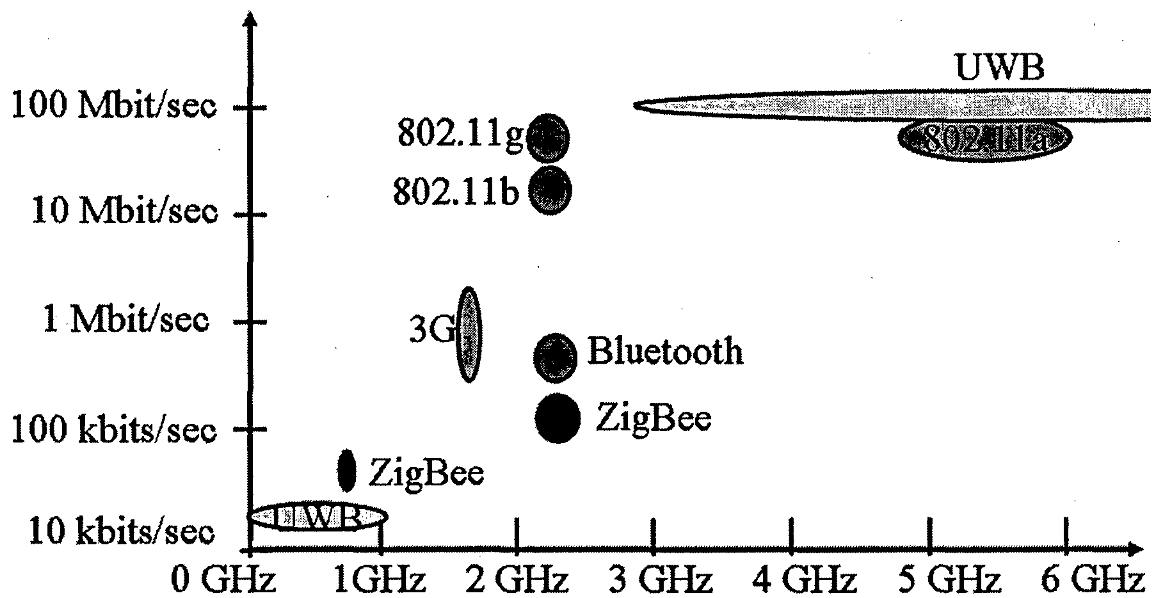


Figure 1. Data Rate

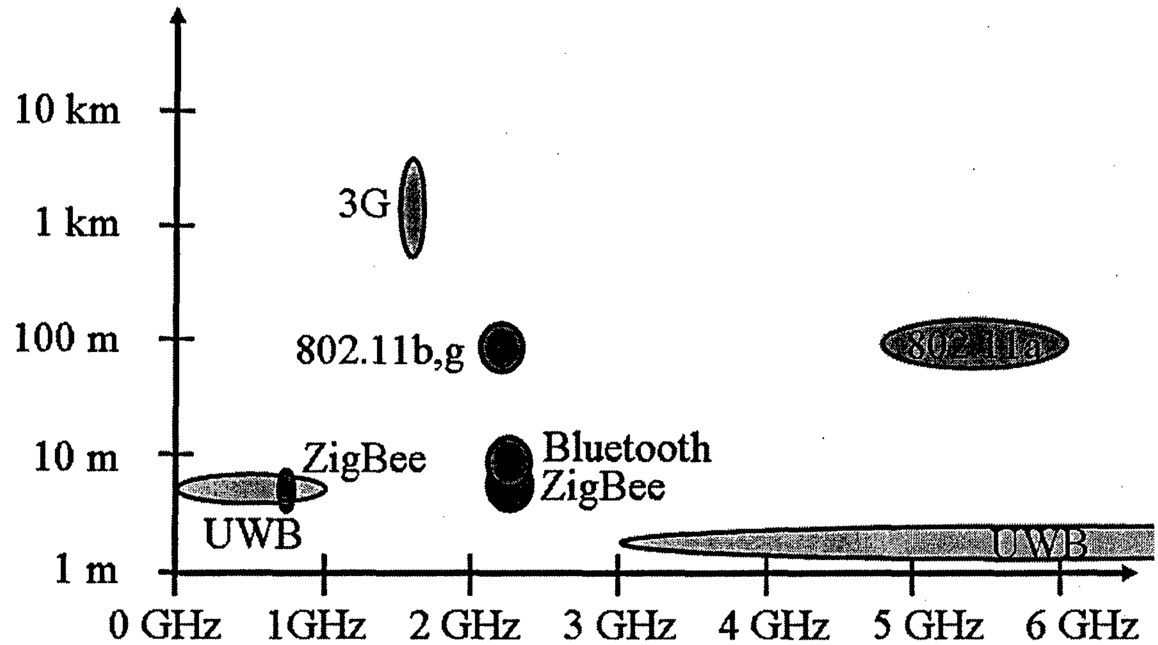

Figure 2. Range

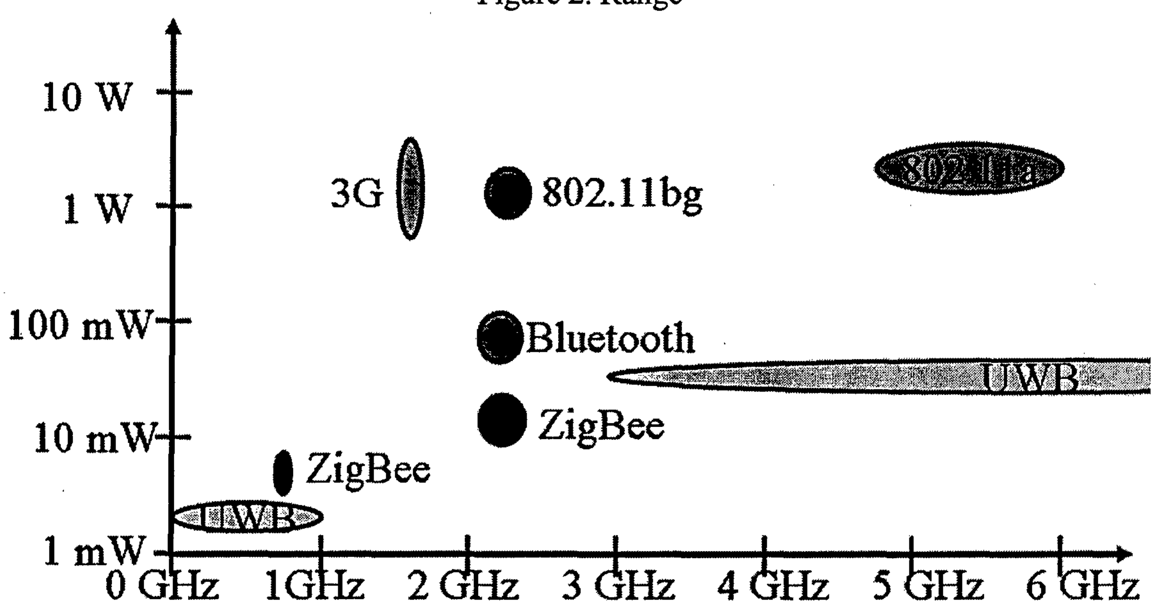

Figure 3. Power Dissipation

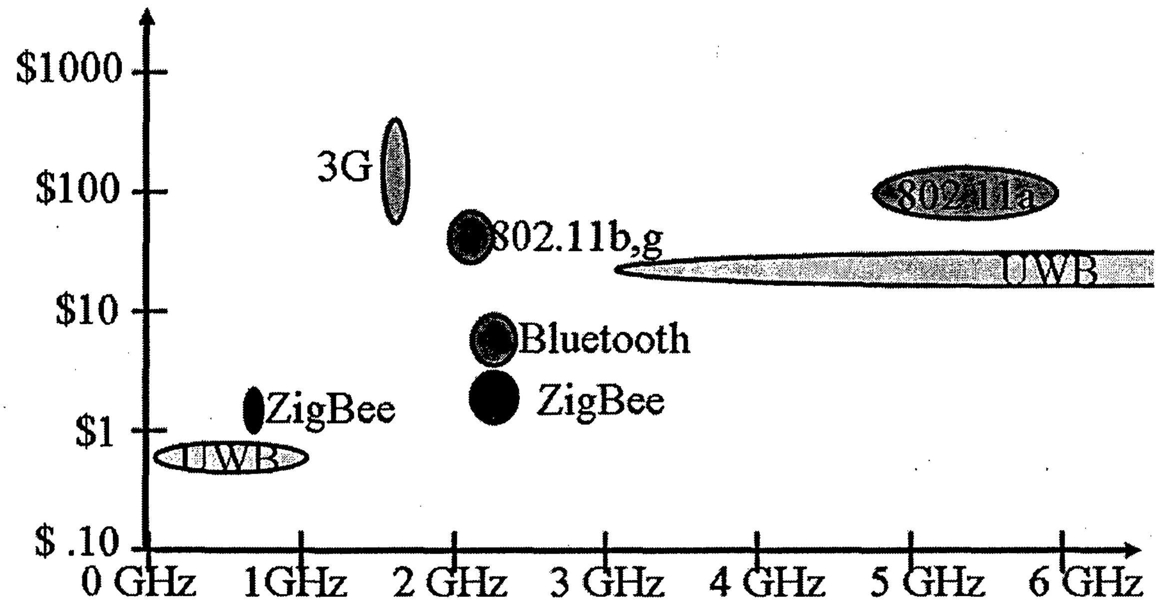


Figure 4. Cost (Projections)

5.1. Contrast in Commercial versus Military Tactical Environment

The wireless communication will be used increasingly in future in both commercial and military environments. However, their emphasis will be different for the two applications. For commercial applications, it is important that the use of wireless communication results in higher profitability for most of the business cycles. For defense applications, it is important that the information transmitted be authentic, accurate, secure, and available under a full range of threats. Figure 5. shows a contrast in commercial versus military tactical environment. [6]

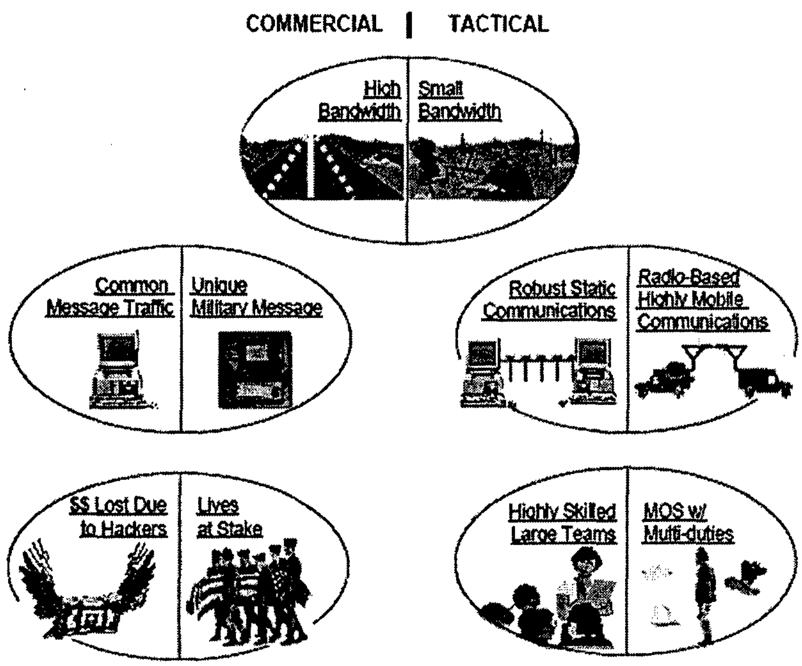


**Figure 5. Contrast in Commercial versus Military Tactical Environments**

## 6. APPLICATION TO HEAD MOUNTED DISPLAY/ TRACKER FOR AIR FORCE APPLICATION

The following section is derived from the internal documents and discussions between Air Force Research Laboratory (AFRL) and the prime contractor, Intelligent Automation, Inc. (IAI):

The use of Helmet-Mounted Display/Tracker (HMD/T) is becoming widespread for air-to-air, within visual range target acquisition. [7:235]

HMD/T provides the aircrew with a significant amount of information on the helmet, which reduces the burden of the aircrew from having to continually look down in the cockpit to receive information. HMDs allow the aircrew to receive flight and targeting information regardless of line-of-sight, which should increase the aircrew's situation awareness and mission effectiveness. [8:11]

### 6.1. Problem

Current technology requires that a pilot wearing a Helmet Mounted Display/Tracker be connected to the aircraft with a cable. The cable transfers control information, tracking data, and display data between the aircraft and the helmet. The design of this cable is complex, costly, and can decrease system reliability. Additionally, multiple power conductors are required. The entire cable system must incorporate a reliable and safe disconnect type of connector that permits automatic separation during ejection or emergency ground egress.

## 6.2. Solution

Many of the problems associated with the use of cable can be alleviated by using wireless transmission for all of the video, tracker, and control signals. This will significantly reduce or eliminate the requirements of the interconnect cable/connector reducing system complexity, and cost, and enhance system safety.

## 6.3. System Requirements

The system requirements have been developed keeping in mind the current application for Joint Head Mounted Cueing System (JHMCS) and making provision for the future application for Joint Strike Force (JSF), Strike 21 and the future modified version of JHMCS. The following set of requirements will cover most of these applications:

- Multiple bi-directional video/stroke symbology feeds
- Upto to three color (NTSC) display signals from the aircraft to the helmet display(s)
- One color (NTSC) camera video from the helmet to the aircraft
- Tracker data consisting of three 4.5 Mbit/s digital streams
- Several digital control signals

### 6.3.1. Other Requirements

- Maximum of four feet transmission distance
- 4pi sterradian coverage
- Operation in existing EMI/EMC environment (No EMI problems to the aircraft)
- System should not be capable of being intercepted/exploited
- Head mounted equipment must be small, light weight, and meet head/helmet inertial properties
- Power to the helmet system should be self contained (i.e., battery operated). Possible exception: power supply may be retained via a cable/connector
- A bit error detection and correction scheme
- The final system must be human safe and able to withstand the rigors of fighter/bomber aircraft regimes including high-G maneuvering, emergency ground egress and ejection
- Support for growth to higher resolution displays/imagers

## 6.4. Implementation

Most of the wireless technologies described earlier were considered but only one was considered suitable for this application. It is called bi-directional Ultra Wideband (UWB) wireless link. UWB has several characteristics that make it superior to other existing wireless technologies. The pulses transmitted by UWB essentially transmit at all frequencies within this range simultaneously. Hence, its energy is spread over several Giga Hertz and the power level at any frequency is below the noise level. There is no carrier frequency for adversaries to intercept or exploit, so UWB wireless communication is far more secure than traditional wireless technologies and will not cause interference to existing communication equipment and radar onboard the aircraft. Furthermore, the super narrow pulse used by UWB allows it to avoid the fading problem in high multipath environments. UWB uses long sequence of pulses with pseudo-random code. Its operation can be analyzed by considering the following:

A monocycle is a wide bandwidth signal, with the center frequency and the bandwidth completely dependent upon the pulse's width.

Impulse systems use long sequences of pulses, not single pulses, for communication. (See Figure 6). This is essential so that a large number of pulses can be averaged to obtain the required signal to noise ratio.

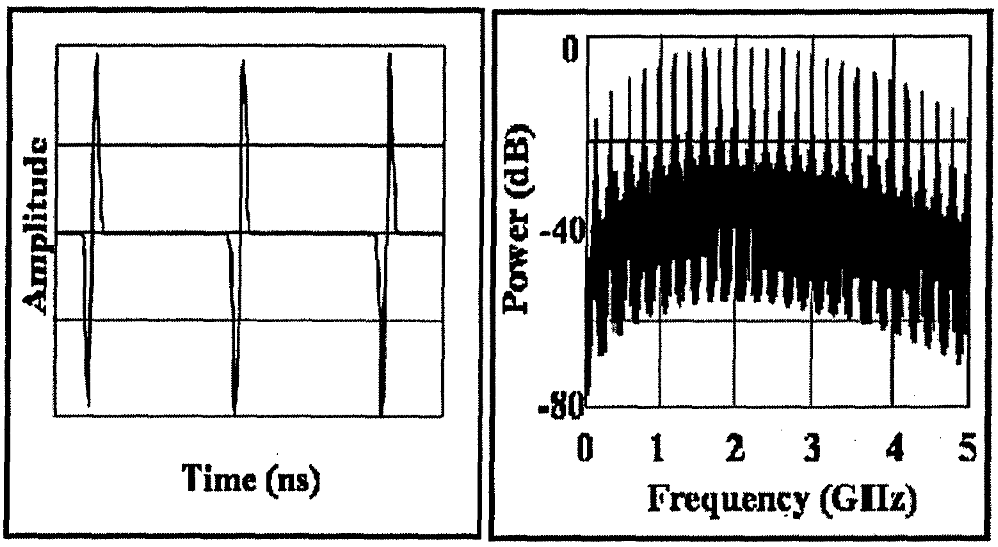


**Figure 6. A monocycle pulse train in the time and frequency domain. Modulation is not used.**

As shown in the right hand graph of Figure 7, pulse modulation distributes the RF energy more uniformly across the band (it smoothes the spectrum of the signal), thus making the system less detectable.

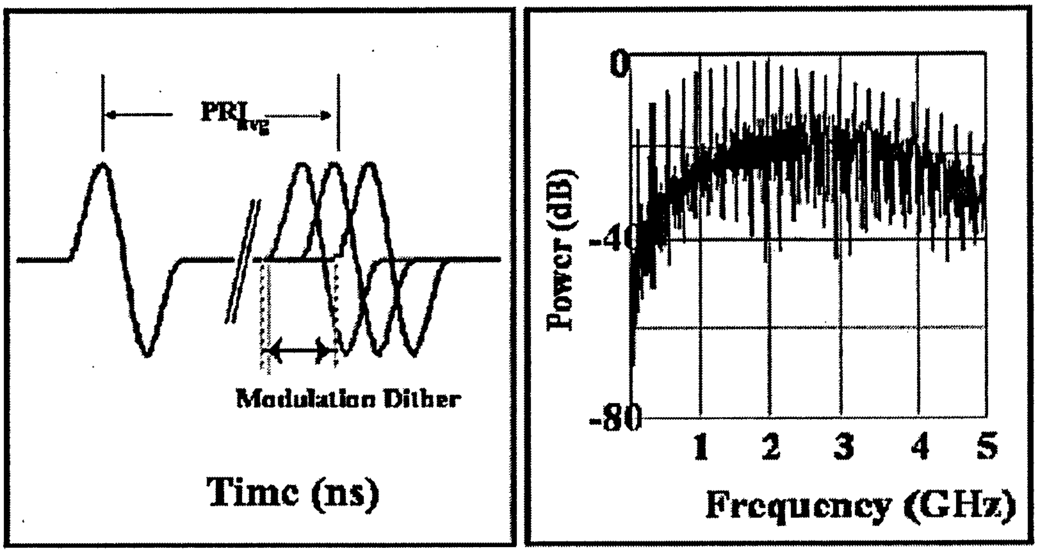


**Figure 7. Pulse Position Modulation**

Pseudo-Random Noise Coding

At this point any modulated pulse train looks like any other pulse train; it is not channelized. However, by shifting each pulse's actual transmission time over a large time frame in accordance with a code, one can channelize a pulse train. As illustrated in Figure 8, the communication chip developer (Time Domain) uses "pseudo-random noise" codes (PN codes) for this purpose. Only a receiver operating with the same pseudo-random code sequence can decode the transmission.

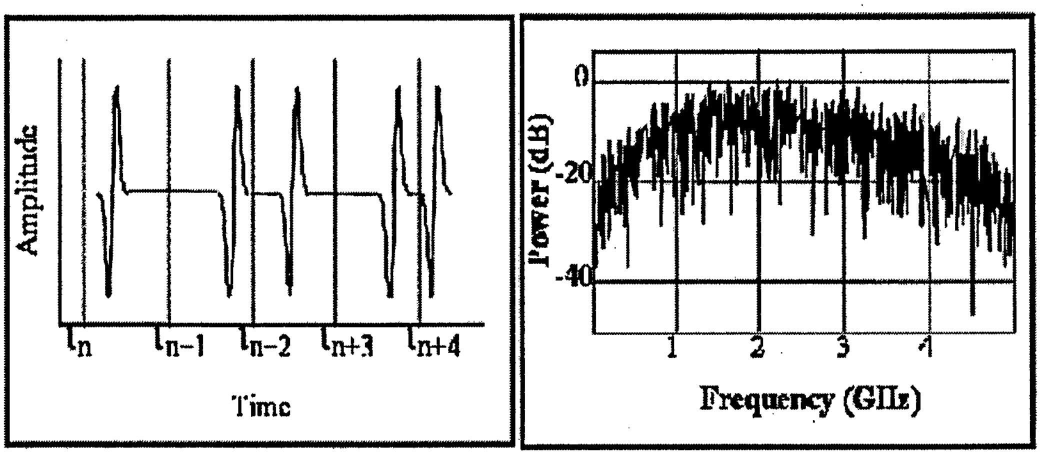


**Figure 8. Pseudo-Random Noise Coding**

Using this UWB technology a prototype was developed to demonstrate the wireless message traffic between the helmet and the aircraft (See Figure 9). The effect was to eliminate a bulky cable that was used to perform this function. Of course, the power to the helmet was supplied separately for this demonstration. Also the data traffic representing the tracker was not used in the simulation for Phase I effort. This is being addressed in the Phase II effort.

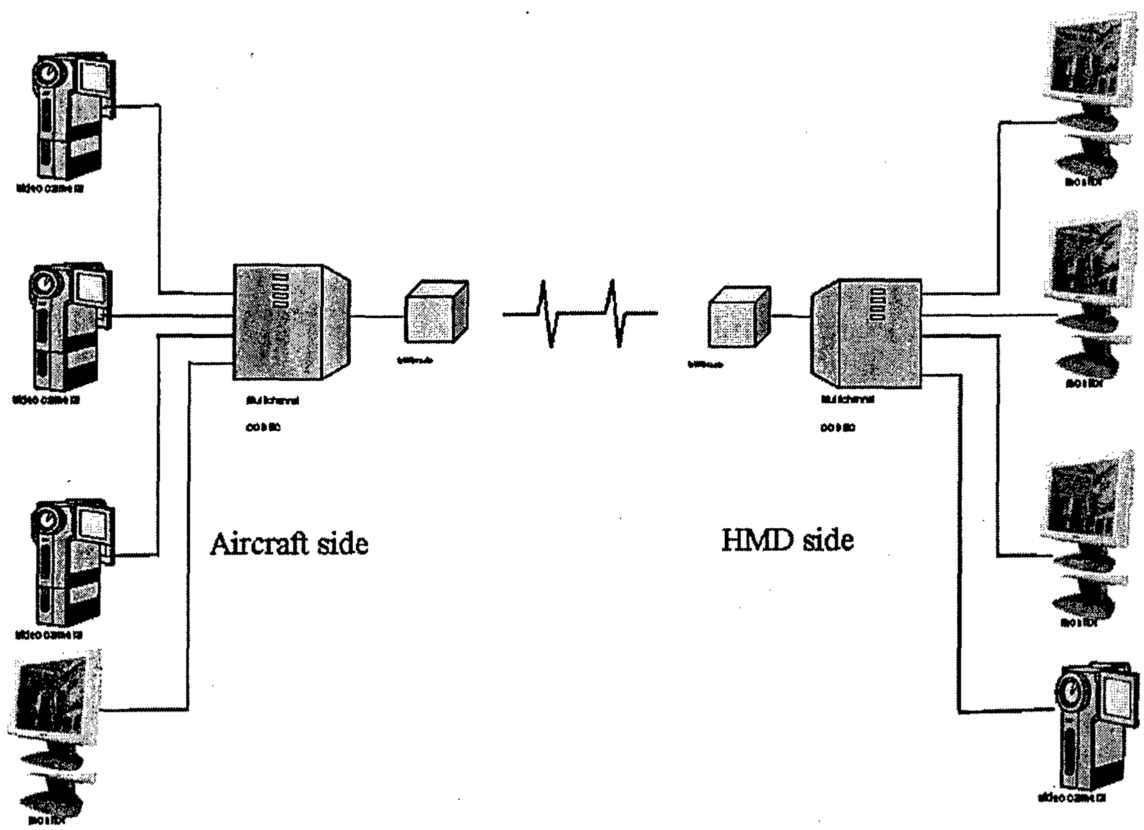


**Figure 9. A Prototype to Demonstrate Wireless Communication on HMD Using UWB**

The target of this application was Joint Helmet Mounted Cuing System (JHMCS). A block diagram for JHMCS is shown in Figure 10. The magnetic-tracker transmit unit (MTU) produces a magnetic field which interacts with three mutually perpendicular coils in the magnetic-tracker receive unit (MRU). The voltages induced in these coils are converted into bit streams and sent to the aircraft tracker/display/camera/control electronics module which averages these signals over a period of time and produces coordinates for the location of the magnetic tracker.

Since no working JHMCS was available, a simulated environment was created as shown in Figure 11. A joystick with two coils is used. The output of this joystick is fed to the joystick processor which produces the corresponding bit streams. These bit streams are padded with additional random noise data to bring the data rate to 2.25 Mb/s which corresponds to the data rate for the magnetic tracker in JHMCS. The sent data and the received data are compared to determine the bit error and its effect on the performance of various units.

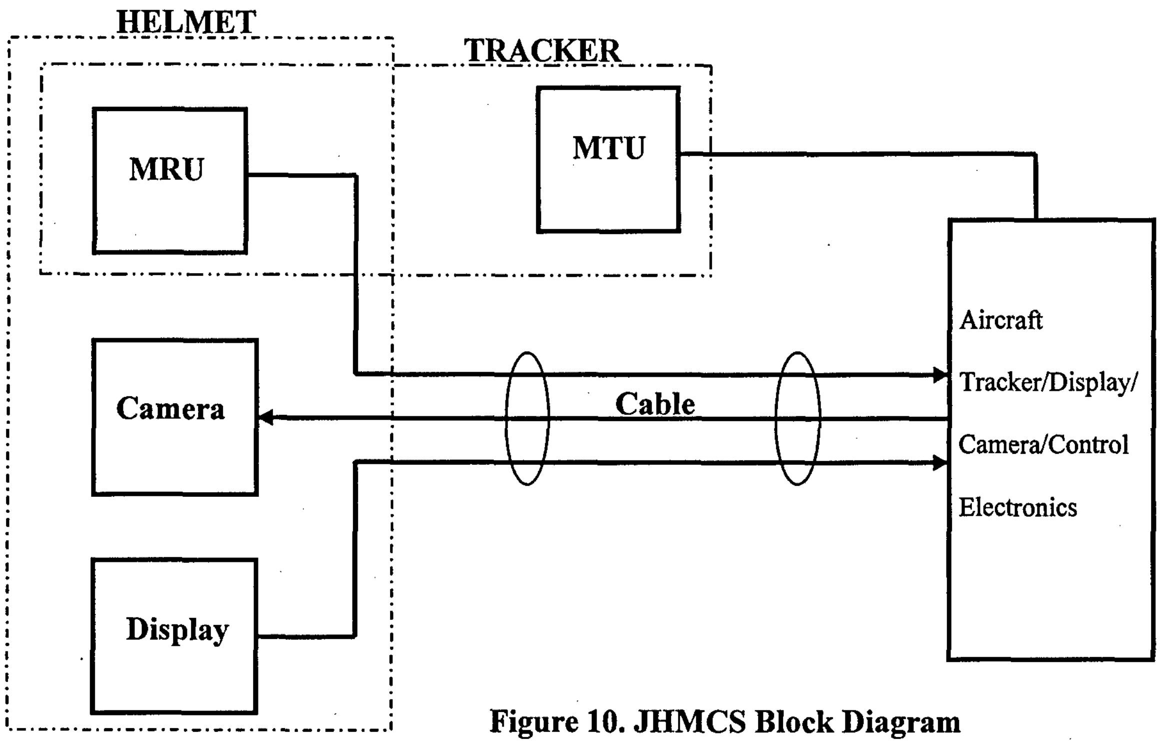


**Figure 10. JHMCS Block Diagram**

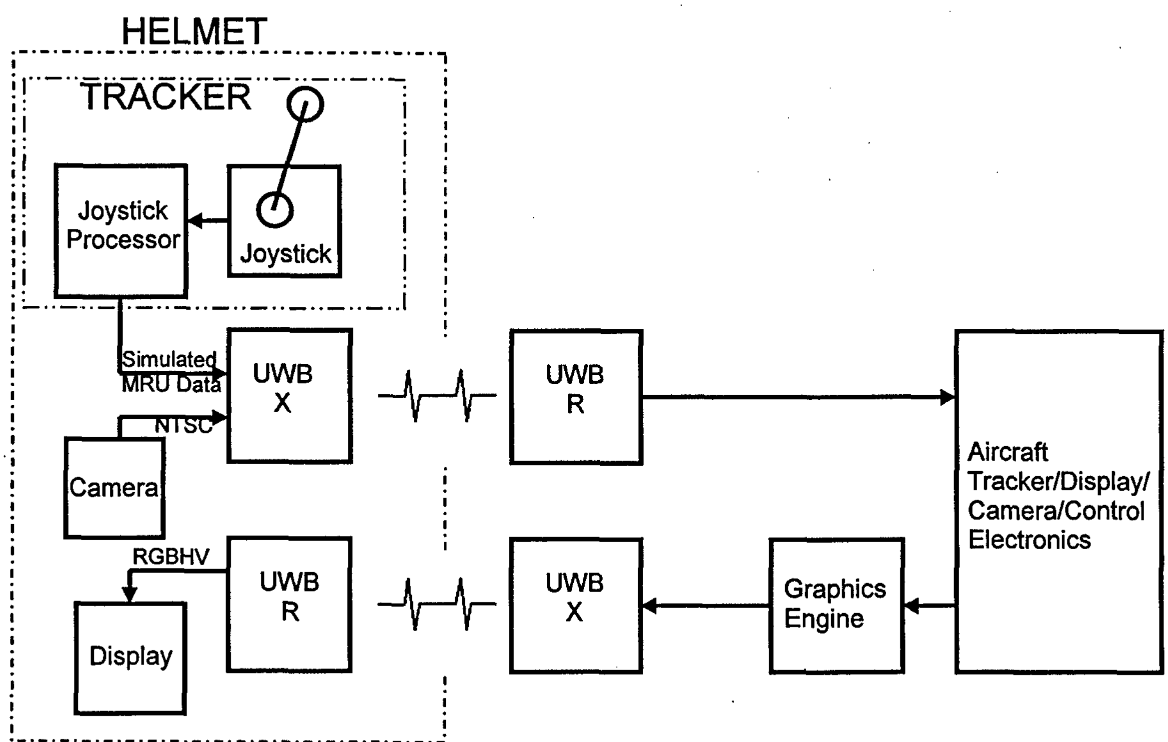


**Figure 11. Simulated JHMCS Block Diagram**

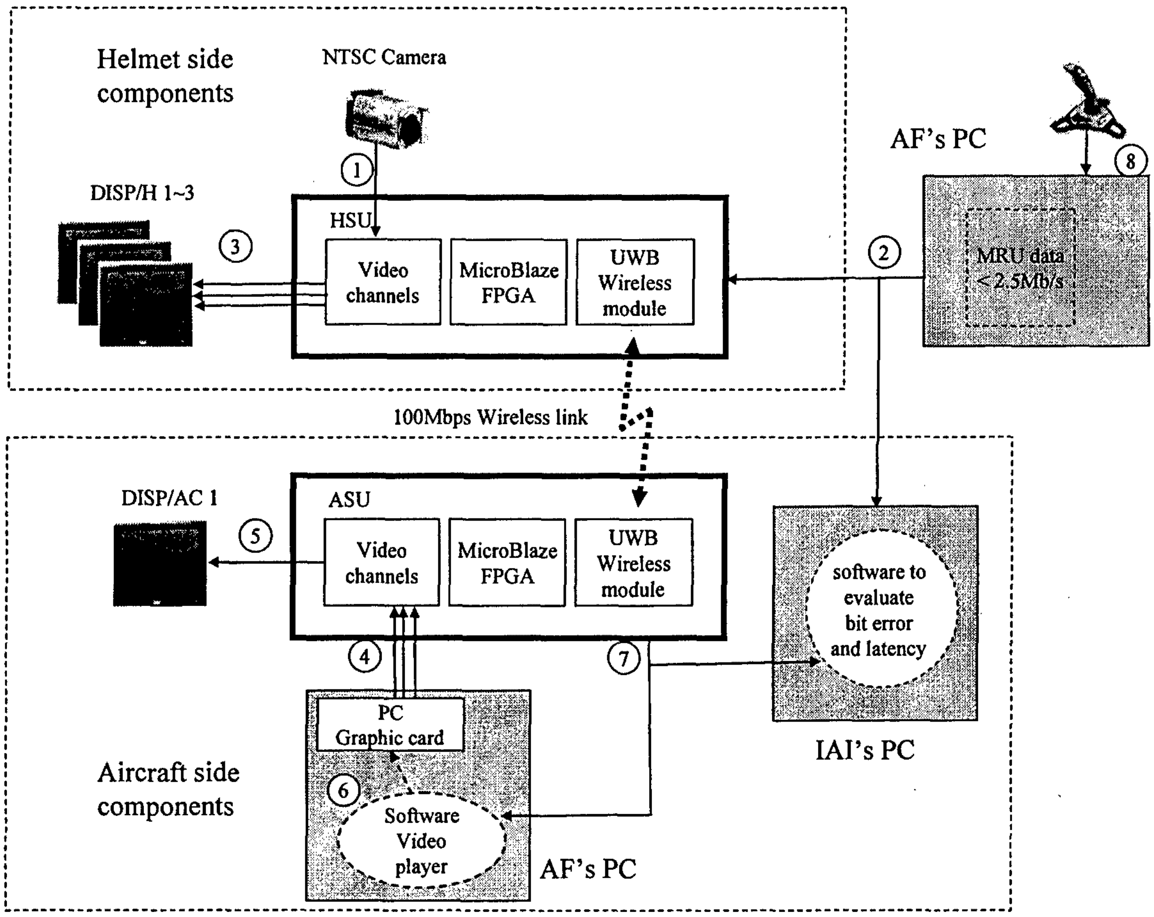


Figure 12. Wireless implementation of simulated JHMCS

Table 2. gives a description of each of the interfaces circled in Figure 12.

| # | Connecting Components | Interface Choices |
|---|---|---|
| 1 | SD camera video output to HSU (Helmet Side Unit) | RS170A i.e. NTSC |
| 2 | MRU data output to HSU and IAI's PC | RS422, supporting upto 2.5Mbps |
| 3 | HSU output received video to helmet mounted display 1~3 (DISP/H 1~3) | Analog RGBHV and DVI, supporting resolution from VGA to XGA |
| 4 | Aircraft side graphic processor output to ASU (Aircraft Side Unit) | AF will use RGBHV output. IAI will provide both RGBHV and DVI inputs in ASU, supporting resolution from VGA to XGA |
| 5 | ASU output video received from the helmet camera to DISP/AC | NTSC |
| 6 | AF graphic processor output to the graphic card | This video will contain the scene, symbology, and tracker indicator. AF will support both RGBHV and DVI |
| 7 | MRU data received by ASU from HSU through wireless link | RS422. This data will be fed to IAI's PC to check error and latency with respect to the original MRU data and AF's PC to merge with the symbology |
| 8 | Joystick output to AF's PC | PC's USB port |

Table 2. Description of interfaces

Time Domain Corporation (TDC) was selected as a subcontractor to provide the wireless communication chip sets for this effort. TDC's earlier version of P200 was successfully used to demonstrate the wireless communication for Phase I of this effort with the data rate of 10 Mb/s. TDC started on the newer version of the chip set to get a data rate of about 40 Mb/s for Phase II application. This newer version called P210 was expected to be ¼ of the size and weight of P200. However, P210 failed to transmit reliably at 40 Mb/s by the expected date. Even though TDC's technology had the advantage of additional functionality such as radar and tracking applications, the basic need for this effort was the reliable wireless transmission at a raw data rate of about 40 Mb/s. Because of the uncertainty involved in the getting P210 evaluation kit from TDC in time for the Phase II, it was decided to look for alternatives as a risk reduction plan. Table 3. shows a list of various possible alternative vendors for this task. The technology used, the speed obtained and planned, the chip set, and the current status of the availability of their hardware are also shown. Even though a large number of vendors were capable of performing this task, very few were actually available. The main reason of this problem was that most of these vendors were OEM vendors and were not interested in quantities of 1's and 2's. Finally one vendor (WISAIR) has agreed to support this effort and is the most likely candidate unless TDC comes up with a reliable P210 chip set in the near future.

| Vendor | Technology | Speed | Planned Speed | Chip Set | Current Status |
|---|---|---|---|---|---|
| Alereon (spinoff from TDC) | MB-OFDM | 480Mb/s | | (2)RF, MAC/baseband | Chip available in Q1 2005, no evaluation kit yet |
| Wisair | MB-OFDM | 480Mb/s | 1Gb/s | (2)RF, MAC/PHY | EVK available as discussed currently 100 Mb/s, $30K |
| Staccato | MB-OFDM | 480Mb/s | | (1)RF/PHY/MAC | EVK available, 2U chassis |
| XtremeSpectrum (Motorola) | DS-UMB | 110Mb/s | | (4)RF(2), baseband, MAC | Sample available, EVK ~$50K |
| Freescale (Motorola) | DS-UMB | 114Mb/s | 1Gb/s | (3)RF, PHY, MAC | FCC certified, 110M chip available, Q3 2004, 1G chip 2005 |
| PulseLink | Impulse | 400Mb/s | 1Gb/s | | 1G chip planned to release mid-2005, demo radio available |
| TDC | Impulse | 400Mb/s | 1Gb/s | (3) Timer, Correlator, Baseband | Chip and EVK available, $4K per radio in 2004 |

Table 3. Possible UWB vendors in addition to TDC

## 7. FUTURE PLANS

It is planned that, when a working helmet for JHMCS is available, this wireless technology will be applied in an operational environment. In the meantime, efforts will also be made to adapt this technology for Joint Strike Fighter (JSF) program where the requirements are far more stringent. JSF requires the use of two displays and data transmission rates upto 18 Mb/s.

The current arrangement does not require the cable to be completely removed. The power to the helmet can still be supplied by a cable. However, this cable will be much smaller, lighter and less complex. This is an intermediate step. The final solution will require that no cable at all be used for any purpose. This will necessitate some self-contained power source in the helmet. One solution is to use a battery pack to provide adequate power to reliably complete the mission without excessively loading the pilot with heavier helmet. Another option is to use a fuel cell. This technology has made a lot of progress and has reached a stage where it can be considerable a viable option. This is corroborated by the following announcement:

A small British company is claiming a breakthrough with a new design of fuel cell which is a tenth of the size of existing models and small enough to replace the conventional batteries in laptop computers. This design which is based on new type of fuel stack that mixed air and fuel will run four times longer than conventional batteries and the fuel cell can be instantly recharged. [9]

## 8. ACKNOWLEDGEMENTS

The author thanks Chujen Lin of Intelligent Automation for supplying some relevant documents and Dave Post and Vince Parisi of AFRL for their input.

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